JOURNAL
OF THE
WASHINGTON ACADEMY OF SCIENCES

VOL. 16 AUGUST 19, 1926 No. 14

MATHEMATICS.—*Transformations associated with the Lorentz group and their invariants.*[1] CHARLES BARAFF, U. S. Patent Office.
(Communicated by L. H. ADAMS.)

The aim of the scientist is duofold; first to describe the processes of flux in Nature by means of transformation equations, then to reveal amidst this continual change those entities that are immutable and unchangeable. In an address to the British Association for the Advancement of Science, MacMahon,[2] the president of Section A, called attention to this aim and emphasized its importance in the following words,

"In any subject of inquiry, there are certain entities, the mutual relations of which under various conditions it is desirable to ascertain. A certain combination of these entities may be found to have an unalterable value when the entities are submitted to certain processes or are made the subjects of certain operations. The theory of invariants in its widest scientific meaning determines these combinations, elucidates their properties and expresses results when possible in terms of them. The great principle of chemical science which asserts that when elementary or compound bodies combine with one another the total weight of the materials is unchanged, illustrates one case in point. Another illustration is a fundamental principle in physics,—that when a given mass of an ideal gas is under the operation of varying pressure and temperature the quantity $\frac{pressure \times volume}{temperature}$ is invariant."

With the advent of the theory of relativity in recent years with a scheme of transformations radically different from the transforma-

[1] Received February 19, 1926.
[2] Report Brit. Assoc. Adv. Sci. 1901.

tions of classical physics, the question naturally arises as to the nature of the invariant entities associated with it. The most fundamental invariant of this theory is the interval between two world events. Some other special invariants are the velocity of light through vacuous space and electric charge. It is the aim of this paper in continuation of the results presented in a former paper[3] to elucidate some of the quantities and expressions that remain invariant to a special relativity transformation. The results are set down in a mathematical way with little or no comment. Their physical interpretation is reserved for a future paper.

In what follows most of the transformations are taken from Einstein's original paper of 1905 on the special relativity theory. The invariants are derived by the methods outlined in Wright's *Invariants of Quadratic Differential Forms.*[4]

The invariants which are derived constitute a set of independent invariants from which other dependent invariants may be derived by the ordinary processes of algebra and calculus.

The scheme of notation is as follows: the quantities accented are those that are observed by an observer moving uniformly relatively to a second observer, who represents the corresponding magnitudes by unaccented symbols.

All references to light include any radiation which is propagated through vacuum with the velocity $c$ given by the ratio of the electromagnetic to the electrostatic unit.

## I. KINEMATICAL TRANSFORMATIONS AND THEIR INVARIANTS

In the former paper[5] the transformations for velocities and accelerations were given.

It may be noted that the most general function of the space time coordinates, that remains invariant to the transformation of space time coordinates is

$$F\,(x^2 - c^2t^2,\ y,\ z) \tag{1}$$

Similarly, the most general invariant function which involves velocities only is

$$F\left(\frac{\sqrt{c^2 - u_x^2}}{u_y},\ \frac{u_y}{u_x}\right) \tag{2}$$

where $F$ is any arbitrary function of the arguments.

[3] This JOURNAL, 16: 81–87. 1926.
[4] WRIGHT, *Invariants of Quadratic Differential Forms.* 1908.
[5] *Op. cit.*

It may also be noted that the invariants of the accelerations are deducible as the solutions of the simultaneous equations

$$\frac{-du_x}{1-\frac{u_x^2}{c_2}} = \frac{du_y}{u_x u_y} = \frac{du_z}{u_x u_z} = \frac{dw_x}{3u_x w_x} = \frac{dw_y}{2u_x w_y + u_y w_x} = \frac{dw_z}{2u_x w_z + u_z w_x} \tag{3}$$

There are five independent solutions, three of which are

$$\frac{\sqrt{c^2 - u_x^2}}{u_y}, \qquad \frac{u_y}{u_z}, \qquad \frac{w_x}{\left(1 - \frac{u_x^2}{c^2}\right)^{3/2}}.$$

The other two will follow from the complete integration of these equations. The form of

$$\frac{w_x}{\left(1 - \frac{u_x^2}{c^2}\right)^{3/2}}$$

is of interest, for it has the form of a space time curvature

$$\frac{\frac{d^2x}{dt^2}}{\left(1 - \left(\frac{dx}{dt}\right)^2 / c^2\right)^{3/2}} \tag{12}$$

In the theory of the radiation from electrons, it is sometimes necessary to go one derivative further and consider third derivatives of the space with respect to the time, or the time rate of change of acceleration, which is the equivalent. We will denote the derivative of the acceleration with respect to the time by the symbol $K$. Its component parallel to the $X$ axis is transformed by means of the equation

$$K_x' = \frac{K_x}{\beta^4\left(1 - \frac{v\,u_x}{c^2}\right)^4} + \frac{3\,w_x^2\,v}{\beta^4\left(1 - \frac{v\,u_x}{c^2}\right)^5} \tag{13}$$

The invariant involving it, the acceleration and the velocity is

$$\frac{3\,W_x^2\,U_x - K_x\left(1 - \frac{u_x^2}{c^2}\right)}{\left(1 - \frac{u_x^2}{c^2}\right)^3} \tag{14}$$

This section will be concluded with the transformations for momenta $G$ and Gibb's heat function $R$, which were deduced by Planck[6] from a combination of the *principle of least action* with the *principle of relativity*.

The transformations of these quantities are:

$$G_x' = \beta\left(G_x - \frac{v}{c}\frac{R}{c}\right) \qquad G_y' = G_y \quad G_z' = G_z$$

$$\frac{R'}{c} = \beta\left(\frac{R}{c} - \frac{v}{c}G_x\right)$$

Here $G$ denotes momenta, $R$ denotes the Gibb's Heat Function under constant pressure

$$R = E + pV$$

where $E$ denotes the total energy of the body, $p$ the pressure acting on it, $V$ its volume.

The fundamental invariant involving these two quantities $G$ and $R$ is:

$$\frac{R^2}{c^2} - G_x^2$$

or

$$\frac{(E + pV)^2}{c^2} - G_x^2$$

These transformations may be written in the equivalent form

$$\frac{R'}{c} + G_x' = e^{i\vartheta}\left(\frac{R}{c} + G_x\right)$$

$$\frac{R'}{c} - G_x' = e^{-i\vartheta}\left(\frac{R}{c} - G_x\right)$$

and the invariant therefor in the form

$$\left(\frac{E + pV}{c} - G_x\right)\left(\frac{E + pV}{c} + G_x\right)$$

[6] PLANCK, *Ann. d. Physik:* 1. 1903.

## II. ELECTRODYNAMIC TRANSFORMATIONS AND THEIR INVARIANTS

Electrodynamic quantities are transformed, according to the special theory of relativity, by means of the scheme of transformation identities:

$$\left.\begin{aligned} X' &= X & L' &= L \\ Y' &= \beta\left(Y - \frac{v}{c}N\right) & M' &= \beta\left(M + \frac{v}{c}Z\right) \\ Z' &= \beta\left(Z + \frac{v}{c}M\right) & N' &= \beta\left(N - \frac{v}{c}Y\right) \\ \rho' &= \beta\left(1 - \frac{v\,u_x}{c^2}\right)\rho \\ u_x' &= \frac{u_x - v}{1 - \frac{u_x\,v}{c^2}} \\ u_y' &= \frac{u_y}{\beta\left(1 - \frac{u_x\,v}{c^2}\right)} \\ u' &= \frac{u_z}{\beta\left(1 - \frac{u_x\,v}{c^2}\right)} \end{aligned}\right\} \quad (1)$$

These symbols have the same significance and meaning that is ordinarily attached to them in the fundamental Maxwell-Lorentz equations:

$$\left.\begin{aligned} \frac{1}{c}\left(\frac{\partial E}{\partial t} + \rho\,u\right) &= \mathbf{curl}\ H \\ \frac{1}{c}\frac{\partial H}{\partial t} &= \mathbf{curl}\ E \\ \mathbf{div}\ E &= \rho \\ \mathbf{div}\ H &= 0 \end{aligned}\right\} \quad (2)$$

The transformation identities for the electric and magnetic intensities may be exhibited in somewhat different form by letting

$$\theta = \tan^{-1}\frac{v\,i}{c} = \cos^{-1}\beta$$

in which case, the equations have the form

$$\left.\begin{aligned} X' &= X \\ L' &= L \\ Y' &= Y\cos\theta + Ni\sin\theta \\ N' &= N\cos\theta + Yi\sin\theta \\ Z' &= Z\cos\theta - Mi\sin\theta \\ M' &= M\cos\theta - Zi\sin\theta \end{aligned}\right\} \quad (3)$$

These equations may be derived by integrating the system of simultaneous differential equations

$$\frac{dX'}{0} = \frac{dY'}{-N'} = \frac{dZ'}{M'} = \frac{dL'}{0} = \frac{dM'}{Z'} = \frac{dN'}{-Y'} = \frac{c\,\delta\,v}{c^2 - v^2} \quad (4)$$

with the initial conditions that when $v = 0$, then

$$\begin{aligned} X' &= X \\ Y' &= Y \\ Z' &= Z \\ L' &= L \\ M' &= M \\ N' &= N \end{aligned}$$

There are five independent invariants of electric and magnetic intensity. They are

$$\left.\begin{aligned} &X \\ &L \\ &Y^2 - N^2 \\ &Z^2 - M^2 \\ &\frac{YM + ZN}{MN + YZ} \end{aligned}\right\} \quad (5)$$

The most general invariant function of electric and magnetic intensities is an arbitrary function of these, namely, the function

$$F\left(X,\ L,\ Y^2 - N^2,\ Z^2 - M^2,\ \frac{YM + ZN}{MN + YZ}\right) \tag{6}$$

As a special example of an invariant function of electric and magnetic intensities, it might be interesting to note in passing, the Lagrangian function

$$(X^2 + Y^2 + Z^2) - (L^2 + M^2 + N^2)$$

Let us consider now the transformation identities for $\rho$, $u_x$, $u_y$, $u_z$. The system of differential equations from which these may be derived by integration are

$$\frac{-\,du_x'}{1 - \frac{u_x'^2}{c^2}} = \frac{du_y'}{\frac{u_x' u_y}{c^2}} = \frac{du_z'}{\frac{u_x' u_z'}{c^2}} = \frac{-\,d\rho'}{\frac{u_x' \rho'}{c^2}} = \frac{\delta v}{1 - \frac{v^2}{c^2}}$$

with the familiar condition that when $v = 0$ then

$$\rho' = \rho$$

$$u_x' = u_x$$

$$u_y' = u_y$$

$$u_z' = u_z$$

The independent invariants involving $\rho$, $u_x$, $u_y$, $u_z$ only are

$$\left.\begin{array}{c} \dfrac{u_y}{u_z} \\ \rho\, u_y \\ \rho \sqrt{c^2 - u_x^2} \end{array}\right\} \tag{7}$$

The most general function of these which is invariant to the Lorentz transformation and the associated transformations above is:

$$F\left(\rho\, u_y,\ \frac{u_y}{u_z},\ \rho \sqrt{c^2 - u_x^2}\right) \tag{8}$$

At this point, the question arises as to the form of the most general invariant function of the ten quantities that enter into the Maxwell-

Lorentz equations of electro-dynamics. There are nine independent invariants

$$\left.\begin{array}{c} X \\ L \\ Y^2 - N^2 \\ Z^2 - M^2 \\ \dfrac{YM + ZN}{MN + YZ} \\ \dfrac{(N + Y)\,(c + u_x)}{(N - Y)\,(c - u_x)} \\ \dfrac{u_y}{u_x} \\ \rho\, u_y \\ \rho \sqrt{c^2 - u_x^2} \end{array}\right\} \quad (9)$$

from which the most general invariant function is derived by taking an arbitrary function of these, to wit

$$F\left(X, L, Y^2 - N^2, Z^2 - M^2, \frac{YM + ZN}{MN + YZ}, \frac{(N + Y)\,(c + u_x)}{(N - Y)\,(c - u_x)}\right.$$

$$\left.\frac{u_y}{u_x}, \rho\, u_y, \rho \sqrt{c^2 - u_x^2}\right)$$

### III. OPTICAL TRANSFORMATIONS AND THEIR INVARIANTS

The quantities that appear in the expression for the light vector

$$\sin \omega \left(t - \frac{l\,x + m\,y + n\,z}{c}\right)$$

are transformed by means of the set of equations:

$$l' = \frac{l - \frac{v}{c}}{1 - l\frac{v}{c}}$$

$$\left.\begin{aligned} m' &= \frac{m}{\beta\left(1 - l\frac{v}{c}\right)} \\ n' &= \frac{n}{\beta\left(1 - l\frac{v}{c}\right)} \\ \omega' &= \beta\,\omega\left(1 - l\frac{v}{c}\right) \end{aligned}\right\} \quad (1)$$

The differential form of this transformation is

$$\frac{-\,\mathrm{d}\,l'}{1 - l'^2} = \frac{\mathrm{d}\,m'}{l'\,m'} = \frac{\mathrm{d}\,n'}{l'\,n'} = \frac{\mathrm{d}\,w'}{-\,\omega'\,l'} = \frac{c\,\delta\,v}{c^2 - v^2} \quad (2)$$

with the usual initial conditions.

There are three independent expressions of these quantities that are invariant under the Lorentz transformation. They are

$$m/n \qquad \frac{m}{\sqrt{1 - l^2}} \qquad n\,\omega \quad (3)$$

The most general invariant involving these quantities only is an arbitrary function of the three invariants, to wit

$$F\left(\frac{m}{n}, \frac{m}{\sqrt{1 - l^2}}, n\,\omega\right) \quad (4)$$

If we take cognizance of the electro-magnetic origin of light through the equations

$$\left.\begin{aligned} X &= X_0 \sin\Phi \qquad L = L_0 \sin\Phi \\ Y &= Y_0 \sin\Phi \qquad M = M_0 \sin\Phi \\ Z &= Z_0 \sin\Phi \qquad N = N_0 \sin\Phi \\ \Phi &\equiv \omega\left(t - \frac{l\,x + m\,y + n\,z}{c}\right) \end{aligned}\right\} \quad (5)$$

then we are enabled to consider the transformation equations of

amplitude and energy of radiation. Their transformation equations have the form:

$$\left.\begin{aligned} A' &= \beta\left(1 - \frac{v}{c}l\right)A \\ E' &= \beta\left(1 - \frac{v}{c}l\right)E \end{aligned}\right\} \quad (6)$$

Their corresponding differential form is:

$$\frac{\mathrm{d}\,A'}{-A'\,l'} = \frac{\mathrm{d}\,E'}{-E'\,l'} = \frac{c\,\delta\,v}{c^2 - v^2} \quad (7)$$

Let us consider at this point the question of finding the invariant expression that involves the energy and frequency of a radiation only. It is the solution of the differential equation

$$\frac{\mathrm{d}\,E}{-E\,l} = \frac{\mathrm{d}\,\omega}{\omega\,l}, \text{ namely } \frac{E}{\omega} \quad (8)$$

This is a significant result. A priori, the invariant might have been a sum or product or any other conceivable function of the quantities $E$ and $\omega$, but that it turned out to be the ratio $\frac{\textit{Radiation Energy}}{\textit{frequency}}$ the quantum, is very significant for the relativity theory from which it is derived. Einstein, in his original paper on the special theory of relativity, declared that it was remarkable that the energy and frequency of a light complex should both vary in the same manner as a result of changes in the state of motion of the observer.

It might be of some interest to gather together here the independent invariants of the most important quantities that present themselves in optical phenomena, such as the frequency of the radiation, the direction of the wave normal, the amplitude, the energy of the radiation. They are derivable from the equations

$$\frac{-\mathrm{d}\,l}{1-l^2} = \frac{\mathrm{d}\,m}{l\,m} = \frac{\mathrm{d}\,n}{l\,n} = \frac{\mathrm{d}\,\omega}{-\omega\,l} = \frac{\mathrm{d}\,A}{-A\,l} = \frac{\mathrm{d}\,E}{-E\,l}$$

as the solutions thereof. The invariants are

$$\left.\begin{array}{c} \dfrac{m}{n} \\ \dfrac{m}{\sqrt{1-l^2}} \\ n\,\omega \\ \dfrac{E}{\omega} \\ \dfrac{E}{A} \end{array}\right\} \quad (9)$$

The general invariant function of these quantities is:

$$F\left(\frac{m}{n}, \frac{m}{\sqrt{1-l^2}}, n\,\omega, \frac{E}{\omega}, \frac{E}{A}\right) \quad (10)$$

In closing, I wish to express my indebtedness to my sister Ella for the inspiration she has been to me in this work.

GEOLOGY.—*On the geological age of Pleistocene vertebrates found at Vero and Melbourne, Florida.*[1] OLIVER P. HAY, Washington, D. C.

For a number of years I have been studying the vertebrates of the Pleistocene of North America and their relations to the deposits of this epoch. I have recognized, with others, that at the beginning of the Pleistocene there was a fauna extremely rich in genera and species, composed in part of animals native to the continent, in part of immigrants from Asia, and in part of invaders from South America. When white men arrived here the fauna had become relatively impoverished. Species, genera, and even orders of stately animals had disappeared; and the gaps had not been filled up either by development of new forms or by arrival from other lands. Furthermore, on the basis of the changing composition of the fauna, I have divided[2] the epoch into an Earlier and a Later Pleistocene.

Having reached and announced these conclusions I am impressed that some of my friends, paleontologists, geologists, and anthro-

[1] Received June 10.

[2] This JOURNAL 15: 126–133. 1925.

pologists, doubt the correctness of my views. Conscious of this dissent, I propose to discuss the subject once more.

There are certain animals which I believe characterize the Earlier Pleistocene and are absent from the later half of the epoch. These are the great ground-sloth *Megatherium*, the glyptodons, the camels, *Elephas imperator*, the mastodon *Anancus mirificus*, the great capybaras found in Florida and Texas, certain species of horses, the sabertooth tigers of the genus *Smilodon*, and the gigantic tortoises of the genus *Testudo*. My reasons for believing that these remarkable mammals and reptiles were confined to the early half of the Pleistocene are as follows:

1. They and the deposits containing them have hitherto been regarded by most vertebrate paleontologists and geologists as appertaining to the early part of the epoch or to the Pliocene. Marsh and Cope originally referred what they called the Equus fauna to the upper Pliocene, until Gilbert demonstrated that it belonged in the Glacial epoch. Marsh went so far as to say that two species of *Bison* had been discovered in the Lower Pliocene. This assignment of the deposits containing the Equus fauna is not necessarily correct; but those who reject it are put under obligations to render some reasons for their procedure. Up to the present time, however, they have failed to do this. An exception to this statement is a paper issued recently by Kirk Bryan and J. W. Gidley.[3] This concerns fossil horses, a camel, and *Elephas boreus*, discovered in Arizona. The argument in favor of a late Pleistocene age is based on the shallowness of the bone-bearing deposit.

2. Where from stratification of the deposits the geological age of the animals discussed can be determined they are found to belong to the Early Pleistocene. This demonstration is offered to us along Missouri River in South Dakota, Iowa, and Missouri. Here one or more species of camels, *Elephas imperator*, *Anancus mirificus*, and various species of horses occur between the first and the second drift sheets; that is in first interglacial, or Aftonian, deposits. On the other hand, neither in nor on any later deposit, glacial or interglacial, has *Elephas imperator*, or *Anancus mirificus*, or any camel, or certain species of *Equus*, or any species of *Smilodon* been discovered. Beyond the borders of the glaciated region, on the Great Plains, from South Dakota to the Gulf, camels are found associated with the others of the species mentioned, but never with the abundant and wide-spread existing bison.

[3] Amer. Journ. Sci. 11: 477–488. 1926.

3. The composition of faunas, both of the land and of the sea, is subject to gradual change and has been so subject throughout all time. One species after another drops out of existence. These extinctions occur even when the environment seems favorable and undisturbed. How much then must the mortality have been increased during such an epoch as the Pleistocene, when the animals were subjected alternately to extremes of heat and cold, drought and humidity, abundance of food and scarcity of it. The answer to this is found in the copiousness of the early fauna, the relative poverty of the late.

In the stratum known as No. 2 at Vero and Melbourne occur *Glyptodon*, *Megatherium*, *Chlamytherium*, *Megalonyx*, *Mylodon*, *Equus*, *Tapirus*, *Camelops*, *Elephas imperator*, great dogs of the genus *Aenocyon*, the saber-tooth *Smilodon*, tiger-like species of cats, capabaras of bear-like size, tortoises larger than those from the Galapagos Islands, and many other species of less importance. In 1924 Dr. F. B. Loomis, of Amherst College, published[4] a paper in which he gave it as his opinion that the animals belonged to the late Pleistocene. He offered no reasons for his conclusions. In 1926 Dr. J. W. Gidley, in an abstract of an address on the discoveries made at Melbourne, declared[5] that the "general geologic conditions, as interpreted, suggest a relatively recent date, either late Pleistocene or even post-Pleistocene, for the extinction of the last survivor of the Pleistocene fauna in the south." The geologic conditions requiring this conclusion were not specified. Inasmuch as the animals occurring there were, without doubt, in North America at or soon after the beginning of the Pleistocene it follows that all of them were able to survive the vicissitudes of the Pleistocene and then, when the favorable Recent had arrived, they were by some strange visitation wiped out of existence. The tremendous difference between the early Pleistocene fauna and that of the Recent was then produced. In this connection it would be interesting to learn what important genera and species, in his opinion, became extinct during the early and middle portions of the Pleistocene; also how early Pleistocene deposits are to be distinguished from the latest.

4. As a method of determining the relative ages of deposits paleontologists and geologists have sought to use the percentages of living and extinct species. This practice is based on the conviction that faunas, as time passes, change somewhat gradually their elements.

[4] Amer. Journ. Sci. ser. 5, **8**: 503–508.

[5] This JOURNAL **16**: 310.

A cave in Pennsylvania furnished 28 species, of which 2 (7 per cent) appear to be extinct. Among the existing forms was the caribou. The geological time was probably near the end of the Wisconsin glacial stage. The percentage of extinct species at Vero and Melbourne may be taken as about 70. Which assemblage, the Pennsylvanian or the Floridan, is the older? What now is the value of the percentage method? Perhaps it is to be employed in an inverse sense, the higher the extinct percentage the younger the fauna?

5. Possibly something may be learned about Pleistocene history in North America from that of Europe. Events there ran about the same course as in America; at least, the geologists tell us so. Glacial stages and interglacial there appear to correspond in general with those in America. According to Haug,[6] a French geologist, the Pleistocene was ushered in by an invasion of a new fauna which included elephants, oxen, and horses. The oldest formation is the Villafranchian, of Valle d'Arno, Italy. Haug gives a list of 22 characteristic species. Some of these do not occur in any later lists; others lived on to the middle of the Pleistocene; some to near its end; none now exist. Two genera of mastodons, *Mammut* and *Anancus*, became extinct in the first half of the epoch; a rhinoceros lived only a little beyond the end of the first half. The Cromer Forest bed in England belongs in the Early Pleistocene and furnishes a long list of species. According to Haug's list, 63 per cent of these are extinct, many of them not reaching the end of the first division. In the second division other elephants and rhinoceroses became the prominent elements of the fauna. These statements do not sound much like those which are being brought up to us from Melbourne.

I may be permitted to say, that if we leave the Recent out of Haug's classification of the Quaternary, the remainder is arranged in two divisions which agree quite closely with those of my own arrangement; and this was made before I had learned what Haug had done.

6. I have referred to the fact that *Elephas imperator*, *Anancus mirificus*, the camels, and the saber-tooth *Smilodon* are not found in or on any glacial deposit succeeding the Aftonian. How is this to be explained if those animals continued to exist up to near the present? We have been told that they were able to live near the glacial front and there to mingle with musk-oxen and reindeer from the Arctic. As the Kansan ice sheet receded the megalonyx, the mylodon, the American mastodon, the Columbian elephant, *Elephas boreus*, the musk-oxen, and a host of other species followed the glacier

[6] HAUG, E. *Traité de Geologie*, pp. 1760. 1921.

and occupied their ancient pastures. Why did not the imperial elephant, the mirific mastodon, and the camels do likewise? My explanation is that they no longer existed. My critics may adopt a theory quite opposite their former one and assert that these species had been driven southward where the climate was milder; that they remained there and made their last stand around the Gulf and in Mexico. The geological history of the other elephants, of the American mastodon, of a few species of horses, of the bisons, the peccaries, the wolves, and the giant beaver, contradicts the idea that even the succession of at least four glacial stages and three interglacial changed the habits of the Pleistocene animals. Reindeer and musk-oxen might have remained, if willing, in New England to enjoy the warmer climate, but as fast as the way was cleared for them they betook themselves to the frigid north. *Elephas imperator* has been found as far north as Helena, Montana, and the northwestern corner of South Dakota. I regard these finds as belonging to the Earlier Pleistocene. If of a later time, the species had not been driven south; also, it had not ventured to return to Iowa. Farther south, at Afton, Oklahoma, within less than 300 miles of the glaciated region have been collected 2 species of camels, apparently 5 species of horses, *Elephas columbi*, *E. imperator*, and the common mastodon. All were found not far from the surface, in a spring, associated with numerous flint implements. At whatever Pleistocene stage these animals were buried, the mastodon, the Columbian elephant, apparently one kind of horse, the giant beaver, and others were able to spread over the grassy plains of Missouri, Iowa and Illinois; but these plains had no attractions for the imperial elephant and the camels.

The reluctance to admit the early Pleistocene age of the animals of stratum No. 2 at Vero and Melbourne is due to at least two beliefs. One of these is that the terraces along the coast are of marine origin and have been built up at intervals during the Pleistocene. If this theory is correct the lowest terrace naturally must be regarded as comparatively young. I may be excused for referring to a paper[1] in which I try to show the improbability of a marine origin, because of the utter lack of marine fossils in them, except in the lowest part of the lowest one. On the Pacific Coast there are high and low marine terraces, but they betray their origin by the inclusion of seashells. At many places in Europe are found similar Pleistocene terraces, but they are known to be of marine origin from the fossils they contain. It is wholly improbable that molluscan shells buried

[1] This JOURNAL **14**: 255–264.

in deposits laid down, as on our coast, along such a vast extent of shore, composed of materials of every sort, should, when the deposits are lifted above the sea, be dissolved out without leaving a remnant of shell or a hole where they had been buried. Another factor influencing opinions as to the age of the deposits and fossils at Vero and Melbourne is the presence of men's bones and artifacts. I think I am not wrong in saying that this has been the determining element in this reference of stratum No. 2 to the late Pleistocene or to the post-Pleistocene. It is the olive branch offered to the anthropologists. They may be reconciled to the companionship of man with camels and glyptodons, in case it was only a few thousands of years ago. I do not believe that the late arrival of man in America is a fact so well demonstrated that geology and paleontology must yield unquestioning assent. In case Doctor Gidley has proved that his human remains were originally buried where found, he has demonstrated a much earlier coming of man than he supposes.

BOTANY.—*A new genus of palms based on* Kentia forsteriana.[1] O. F. Cook, Bureau of Plant Industry, U. S. Department of Agriculture.

Lord Howe Island, in the south Pacific, between Australia and New Zealand, has four endemic palms, including two species of commercial importance. For many years the seeds have been collected in large quantities and shipped to Europe and America for raising the seedlings in greenhouses. The species known as *Kentia forsteriana*, with gracefully drooping deep-green leaves, is the most familiar palm in household cultivation.

All of the Lord Howe palms were described originally as species of *Kentia*,[2] but have been transferred to other genera. The two com-

[1] Received July 3, 1926.

[2] Von Mueller, Fragmenta Phytographiæ Australiæ 7: 99. 1870; 8: 234. 1874. The botanical history of the palms of Lord Howe Island can be traced through the writings of Helmsley, Maiden and other authors. The most recent and complete account, with photographs of the palms in their native habitats is by W. R. B. Oliver, "The Vegetation and Flora of Lord Howe Island," Transactions and Proceedings of the New Zealand Institute for 1916, pages 94 to 161, issued December 20, 1917. A list of publications is included, but does not contain citations to the original descriptions of the palms, in 1870 and 1874, nor to the first account of the discovery of the palms by C. Moore, Director of the Sydney Botanic Gardens, which was published in The Gardeners' Chronicle for September 11, 1869, six months in advance of the botanical descriptions. Moore recognized the four kinds of palms on Lord Howe Island as distinct and new, and supplied the material used by von Mueller in naming the species. Von Mueller states that the name *forsteriana* was applied to the Thatch Palm at Moore's request. The paper sent to The Gardeners' Chronicle was dated at the Sydney Botanic Gardens June 16, 1869, and states that three days had been spent on Lord Howe Island.

mercial species have been assigned to *Howea*, as *Howea belmoreana* and *Howea forsteriana*. The name *Kentia* is likely to continue in commercial use, although the commercial Kentias are not closely related to *Kentia procera*, the original species described by Blume in 1836, from New Guinea. Both of the commercial species are growing and fruiting in the open air in California, where comparisons of the adult characters have been made.

The usual household specimens of these palms show only the juvenile characters. Larger size is attained in greenhouses, but the fruiting state apparently is not reached. The propagation of the commercial Kentias has depended entirely upon the imported seed. Recently it is reported that the supplies from Lord Howe Island are endangered by a plague of rats. Though only a few of the palms in California have begun to fruit, they appear well adapted to the coast districts and produce viable seeds.

Baron von Mueller published the original descriptions of the Lord Howe palms in 1870, and gave a correct account of the simple spadix and spathe of *Kentia belmoreana*, showing that the specimen was complete. The inflorescence of *K. forsteriana* was stated to be incomplete, and evidently consisted of a part of one of the branches. Further data were supplied in 1874 in what appeared to be an amended description of *Kentia belmoreana*, but with a compound inflorescence and floral characters different from those of the description of 1870.

The discrepancies may be explained by considering that the data of 1874 relate to *K. forsteriana*, and presumably were intended to supplement the incomplete and informal description of that species in 1870. The mention of *K. belmoreana* instead of *K. forsteriana* may have occurred as a mere accident in writing the name, or possibly through a mistake in labeling specimens. It would not be admitted that the name *K. belmoreana* could be transferred to a different palm by amending the description, even if that had been the author's intention.

The effect of ascribing a compound inflorescence to *K. belmoreana* was to reverse the use of the names, and this may explain the confusion in botanical and horticultural literature. The descriptions and figures of the two species published in *Linnaea* by Wendland and Drude in 1875 also have the names interchanged. The longer fruits and seeds are associated with *K. belmoreana*, whereas they belong to *K. forsteriana*. A leaf-section with the midrib prominent above but not prominent below is assigned to *K. forsteriana*, while in reality such a midrib is characteristic of *K. belmoreana*.

Several writers have doubted or denied that the species were dis-

tinct, perhaps from seeing palms of the same species under both names. Much that has been written of *K. belmoreana* applies rather to the true *K. forsteriana*. The latter is preferred for ornamental use, as being a hardier and a more beautiful palm, especially in the younger stages of growth. The strongly curved rachis and erect pinnae of *K. belmoreana* also afford striking contrasts with the straight rachis and horizontal pinnae of *K. forsteriana*.

Male flowers with about 30 stamens were described by von Mueller in the original account of *Kentia belmoreana* in 1870, while flowers with 50 to 70 stamens were reported in 1874 in connection with the description of the compound inflorescence published under *K. belmoreana*, but apparently relating to *K. forsteriana*, as already explained. Also it appears that the flowers of the compound inflorescence of 1874 had longer anthers than those of the simple inflorescence of 1870.

The Index Kewensis does not cite the original description of *Kentia forsteriana* in 1870, but refers to the name as it appeared in a checklist of palms published in 1878, from which it might be inferred that the species had not been established before. The description of 1870 leaves no doubt of the author's intention to associate the name *K. belmoreana* with the "Curly Palm" of Lord Howe Island, and the name *K. forsteriana* with the "Thatch Palm" or "Flat-leaved Palm," as the species were recognized by the settlers. The local names were significant, because the straight leaves of *K. forsteriana* would lie flat on a roof, while the strongly recurved leaves of *K. belmoreana* would not serve for thatch. The species to which the name *K. forsteriana* belongs, with the flat leaves, compound inflorescences, and other distinguishing features, now appears to be entitled to rank as a separate genus, which is here described. The other species, *K. belmoreana*, with the simple inflorescences and curved leaves, is considered to be the type of *Howea*.

A separation of the two species *K. belmoreana* and *K. forsteriana* from *Kentia* was suggested by von Mueller in 1870 on the ground of the simple inflorescence, which at first was supposed to be a character of both species. The suggestion was adopted by Wendland and Drude in 1875 in establishing a new genus, *Griesebachia*, but that name was preoccupied. Beccari in 1877 replaced *Griesebachia* with *Howeia*, which later authors have modified into *Howea*. While no species was designated as the generic type, *K. belmoreana* was the first and better-known species assigned to *Griesebachia* and *Howea*, and the only one with the simple inflorescence given as a generic character.

**Denea**, new genus

Closely related to *Howea*, but the trunk tall with uneven, oblique leaf-scars; the leaf with a straight rachis and flat, horizontal or drooping pinnae; the inflorescence compound, of several subequal crassate divisions, each inclosed in a separate complete spathe; the flowers and fruits inserted in deep alveoles with the subtending bracts forming prominent indurated rims; the seeds oblong, with a small round operculum; and the seedlings with simple bilobed leaves, not divided into segments, usually with four simple leaves before the appearance of a compound leaf with separate segments.

In *Howea* the trunk is short, with close, horizontal leaf-scars; the leaf has a strongly decurved rachis and erect pinnae, strongly arched or channeled underneath; the inflorescence is simple, with smaller alveoles and thin, subscarious rims; the seeds are obovoid with a large oval operculum embracing the hilum; and the seedling leaves are compound, the first two leaves usually with four separate segments.

Undoubtedly the genera are rather closely related and they are specialized on similar lines for maintaining their existence in extra-tropical oceanic climates. But the differences of habit and structure are definite and of a nature to suggest long-standing evolutionary divergence.

The trunk in *Denea* is taller than in *Howea*, with longer internodes, separated by oblique leaf-scars, the leaf-scars of *Howea* being transverse and close together. Under slathouse conditions the internodes attain a length of 12 cm., but are much shorter in the open. The internodes have a green epidermis that remains alive for several years. The trunks are reported as attaining 60 feet and upward in Lord Howe Island, or about twice as tall as *Howea*.

The leaf-sheaths of *Denea* are resolved along the margins into an abundant network of pale, light-brown fibers, while in *Howea* there is only an open fringe of dark fibers in the upper part of the sheath.

In *Denea* the leaf has a long petiole, with a straight rachis and horizontal or drooping, flat, open-spaced pinnae, while *Howea* has a short petiole, a strongly recurved rachis, and close-set stiffly erect pinnae, deeply channeled underneath and arched in cross-section. The midribs of the pinnae of *Denea* are prominent below as well as above, while those of *Howea* are prominent on the upper side but not underneath. Thus the pinnae of *Howea* have several specialized characters that make it possible for them to stand upright or in ascending positions. The curved rachis and crowded erect pinnae are chiefly responsible for the very peculiar habit of the palm.

The inflorescences of *Denea* are interfoliar, developing from the axils of younger leaves than in *Howea*, but are so persistent as to outlast the leaves, and then appear infrafoliar. Eventually the mature branches, weighted with the close-set fruits, become pendent, though the basal joint of the inflorescence remains upright and appressed to the trunk. The inflorescences of *Howea* appear among the older leaves and at maturity become definitely infrafoliar, with the basal joint greatly swollen and divergent from the trunk.

The inflorescence of *Denea* is branched, while that of *Howea* is simple. The divisions vary in number from 3 to 8, with 5 as the usual

number, and are nearly equal, with no indication that one branch represents a central axis on which the others are inserted. Each branch of *Denea* corresponds to the simple inflorescence of *Howea*, but the several branches have a broad basal joint, 5 to 6 cm. long, in common, as though several simple inflorescences had united their basal joints. Thus the very peculiar inflorescence of *Denea* consisting of several branches, each inclosed in a separate spathe corresponding to the complete spathe of *Howea*, suggests derivation from a palm like *Howea*, with simple inflorescences. If derived from a branching inflorescence of the usual type it would be expected that a complete spathe would include all of the branches, as with the many palms that have complete spathes.

Occasionally a primary branch of the inflorescence is forked above the insertion of the spathe, which then includes the two subdivisions together. As a result of the branching of the inflorescence and of the narrower and more closely crowded fruits, *Denea* is several times as prolific as *Howea*. On one of the branches of a *Denea* inflorescence 340 fruits were counted. The number of alveoles on a branch is about 400.

The spathes of *Denea* are fibrous and persistent, while those of *Howea* are of thinner and more papery texture and deciduous before flowering. The young spathes of *Denea* are whitish, becoming light brown, and apparently do not contain chlorophyll at any stage.

The alveoles of *Denea* are subtended by thickened, indurated, persistent rims, transverse or broadly emarginate in the middle and distinctly notched at the angles, while in *Howea* the rims are thin and often scarious with no distinct notches at the angles. Apparently the rims of *Denea* were developed from the bracts, like those that appear at the base of the spike, below the fertile alveoles. In *Howea* the corresponding bracts of the sterile alveoles are obsolete, or are completely fused to form the very thin transverse rims. It seems that in *Denea* the bracts subtending the alveoles were retained and developed into the prominent rims, while in *Howea* the bracts were suppressed. In both genera there is a large coriaceous bract inside the alveole, apparently subtending one of the male flowers, while the other flowers are subtended by smaller bracts.

The sepals of *Denea* are imbricate and the petals valvate in the male flowers, but in the female flowers the petals also are imbricate and of heavy, indurated texture with densely fringed margins. Surrounding the base of the fruit are three triangular staminodia, somewhat larger in *Denea* than in *Howea*.

The fruits of *Denea* are longer and more gradually pointed at the ends than in *Howea*, with the stigmatic area more prominent. The exocarp is thicker than in *Howea*, especially at the ends, while the endocarp is thinner, smoother and more transparent, so that the branches of the raphe are perceptible through the endocarp. A regular columnar structure is shown when the endocarp is broken, as in *Pseudophoenix*, *Manicaria* and *Phytelephas*.

The seed in *Denea* is longer and narrower than in *Howea*, and often flattened by the mutual pressure of the fruits. The operculum is small and circular in *Denea*, separate from the hilum and scarcely broader. In *Howea* the seed is ovoid and the operculum forms a prominent oval area distinctly broader than the hilum, and embracing it on the sides. The hilum in both genera is rather prominent and with a few coarse pits, much as in *Psuedophoenix* and *Phytelephas*.

The seedlings of *Denea* have simple, bilobed leaves, and usually there are four such leaves before any separation of segments takes place. Usually the fifth leaf is 4-parted. In *Howea* the first two leaves usually have four separate segments, sometimes 6 or 7, while the third and fourth leaves usually have 8 to 10 segments. Sometimes the first leaf and in rare cases the second leaf in *Howea* may be simple, but never the third or fourth leaves, which generally are simple in *Denea*.

The name *Denea* is derived from the Greek adjective *denaios*, meaning long-lived or enduring, in allusion to the remarkably persistent inflorescences and fruits. Instead of reaching a definite period of maturity the fruit-bearing inflorescences may complete their development and remain in place for several years, with the tissues alive and the fruits firmly attached in the deep alveoles, the exocarp green, and the embryo dormant. The seeds also have unusual vitality, if protected from drying. Some of the seeds may germinate in a few months after planting, while others may lie in the ground for three or four years before sprouting. Thus it appears that a decade may elapse between the flower and the germination of the seed.

Specimens of *Denea forsteriana* (F. Muell.) Cook, showing the inflorescences, fruits and seeds, with photographs of the palms growing in the vicinity of San Diego California and details of the structural characters in natural size have been deposited in the U. S. National Herbarium, as record material.

RADIOTELEGRAPHY.—*Long distance radio receiving measurements and atmospheric disturbances at the Bureau of Standards in 1925.*[1] L. W. AUSTIN. Laboratory for Special Radio Transmission Research.[2]

The following is a resume of the measurements made by the Bureau of Standards on long wave, long distance signal intensities at atmospheric disturbances during 1925, with the addition of some comparisons of the field intensities and disturbances from 1922 to the present time.

The method of measurement is the same as has been used in former years, except in the case of reception through disturbances considerably stronger than the signals which, as is well known, tend to reduce the apparent signal strength. The necessary correction under these circumstances is now determined for each individual case by observing an artificial signal of the same apparent strength as the signal being measured both with and without the disturbances. In this determination the artificial signal is introduced directly into the secondary of the receiver (not through the antenna) from a loosely coupled radio frequency generator.

In the first case, the antenna is coupled normally so that the disturbances are received with the artificial signal, then the antenna is replaced by an artificial antenna with exactly the same constants and coupling to the secondary so that the beat note remains unchanged in shifting from one to the other. A simpler method of correction described in the report for 1924 did not prove entirely satisfactory under all circumstances on account of variations in the character of the disturbances.

In April, 1925, Dr. Dellinger, Chairman of the Committee on Measurements and Standards of the American Section of the U. R. S. I., requested the Radio Corporation of America and the Bell Laboratories to bring long-wave field intensity measuring apparatus to Washington for comparison with the apparatus used at the Bureau of Standards. The methods used by the two companies were alike in employing a radio-frequency comparison in which the signal being measured is matched by an artificial signal of adjustable intensity, produced by a local radio-frequency generator.

[1] Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

[2] Conducted jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy.

In the Bell Laboratories system[3] the current for the local signal is first measured and then attenuated in a resistance network and introduced into the coil antenna at its middle point through a 1-ohm

TABLE 1.—APPROXIMATE TRANSMISSION DATA

| | FREQUENCY f | WAVE LENGTH λ | ANTENNA CURRENT I | EFFECTIVE HEIGHT h | DISTANCE d |
|---|---|---|---|---|---|
| | kc. | m | amp. | m | km. |
| LY[a] Bordeaux | 15.9 | 18900 | 540 | 180 | 6160 |
| FU Ste. Assise, Paris | 15.0 | 20000 | 475 | 180 | 6200 |
| FT Ste. Assise, Paris | 20.8 | 14400 | 380 | 180 | 6200 |
| AGW[a] Nauen, Berlin | 16.5 | 18100 | 460 | 170 | 6650 |
| AGS[a] Nauen, Berlin | 23.4 | 12800 | 400 | 130 | 6650 |
| IDG Pisa | 14.2 | 21000 | — | — | 7300 |
| KET[a] Bolinas, San Francisco | 22.9 | 13100 | 670 | 51 | 3920 |
| LPZ Monte Grande, Buenos Aires | 23.6 | 12700 | 600 | 150 | 8300 |
| GBL Leafield, Oxford | 24.4 | 12300 | 260 | 75 | 5900 |
| NAU Cayey, Porto Rico | 33.8 | 8870 | 150 | 120 | 2490 |

[a] Daily antenna current reported. Other antenna currents more or less uncertain.

TABLE 2.—AVERAGE SIGNAL INTENSITY AND ATMOSPHERIC DISTURBANCES FOR LAFAYETTE (LY), STE. ASSISE (FU), NAUEN (AGW), AND PISA (IDG) IN MICROVOLTS PER METER

| 1925 | A.M. | | | | | P.M. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LY | FU | AGW | IDG | Dist. | LY | FU | AGW | IDG | Dist. |
| January | 111.3 | 31.0 | | 45.7 | 33.3 | 168.6 | 56.1 | | 96.7 | 40.0 |
| February | 105.9 | 38.4 | 44.0 | 24.0 | 57.3 | 119.4 | 52.8 | 56.2 | 68.8 | 94.9 |
| March | 118.0 | 51.3 | 51.8 | 43.3 | 70.4 | 108.7 | 38.2 | 52.8 | 50.5 | 146.9 |
| April | 117.8 | 57.0 | 42.8 | 59.7 | 83.4 | 96.7 | 31.0 | 39.3 | 18.0 | 237.1 |
| May | 120.6 | 61.6 | 50.4 | 62.4 | 54.8 | 99.2 | 36.5 | 33.3 | 33.6 | 158.4 |
| June | 106.9 | 50.7 | 54.2 | 52.9 | 60.1 | 84.5 | 24.2 | 20.9 | 19.7 | 239.4 |
| July | 119.5 | 58.4 | 58.1 | 53.9 | 57.1 | 94.0 | 42.5 | 38.1 | 54.0 | 242.2 |
| August | 137.5 | 84.6 | 74.4 | 63.1 | 42.7 | 73.0 | 45.2 | 40.4 | 50.1 | 208.9 |
| September | 140.1 | 83.6 | 78.6 | — | 52.5 | 102.0 | 56.7 | 49.2 | — | 107.6 |
| October | 137.7 | 63.0 | 60.0 | — | 45.9 | 171.0 | 79.8 | 69.7 | — | 73.1 |
| November | 117.1 | 58.9 | 56.0 | — | 41.4 | 206.0 | 87.4 | 80.8 | — | 59.5 |
| December | 124.1 | 54.0 | 52.9 | — | 49.6 | 267.1 | 114.1 | 88.3 | — | 55.9 |
| Average | 121.2 | 57.4 | 56.6 | 50.6 | 54.0 | 132.5 | 55.3 | 51.7 | 48.9 | 138.6 |

resistance; while the Radio Corporation[4] regulates the intensity of the local signal and introduces it by means of a calibrated mutual inductance. The Radio Corporation method is of especial interest

[3] Proc. I. R. E., 11: 115. 1923.
[4] Proc. I. R. E., 11: 661. 1923.

since it is identical in principle with the methods commonly used for radio field intensity measurement in England, France and Germany. At the Bureau of Standards, long-wave field intensities are measured

TABLE 3.—AVERAGE SIGNAL INTENSITY AND ATMOSPHERIC DISTURBANCES FOR STE. ASSISE (FT), POLINAS (KET), NAUEN (AGS), MONTE GRANDE (LPZ) AND LEAFIELD (GBL) IN MICROVOLTS PER METER

| 1925 | A.M. | | | | | | P.M. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | UFT | KET | AGS | LPZ | GBL | Dist. | UFT | KET | AGS | LPZ | Dist. |
| January | 31.9 | 54.2 | 20.0 | 54.2 | — | 26.0 | 44.8 | 52.4 | 34.7 | — | 35.6 |
| February | 35.6 | 45.4 | 24.6 | 57.1 | — | 44.5 | 35.8 | 56.7 | 35.1 | — | 76.2 |
| March | 36.9 | 49.4 | 27.1 | 55.7 | — | 56.8 | 29.4 | 48.0 | 24.4 | 26.8 | 119.1 |
| April | 44.8 | 59.2 | 24.7 | 41.8 | — | 67.3 | 28.0 | 45.9 | 18.8 | 19.7 | 194.2 |
| May | 46.1 | 56.4 | 32.9 | 49.0 | 15.5 | 46.2 | 27.5 | 41.9 | 17.4 | 23.5 | 145.0 |
| June | 46.8 | 53.7 | 37.5 | 40.2 | 17.9 | 51.3 | 18.5 | 23.4 | 16.0 | — | 217.4 |
| July | 45.4 | 58.0 | 35.8 | 39.9 | 19.6 | 42.5 | 28.6 | 36.6 | 21.4 | — | 213.0 |
| August | 53.1 | 62.1 | 46.5 | 45.6 | 23.2 | 32.7 | 28.0 | 43.0 | 22.9 | — | 185.5 |
| September | 50.6 | 70.6 | 48.6 | 45.9 | 21.7 | 38.7 | 33.3 | 46.5 | 24.7 | — | 88.2 |
| October | 47.5 | 66.7 | 35.8 | 44.9 | 21.5 | 38.7 | 46.2 | 69.5 | 38.5 | — | 58.5 |
| November | 41.6 | 63.0 | 28.1 | 50.7 | 17.1 | 34.0 | 56.7 | 65.0 | 38.5 | — | 52.2 |
| December | 48.5 | 70.4 | 24.1 | 60.3 | 23.6 | 41.6 | 71.3 | 78.0 | 49.2 | — | 48.5 |
| Average | 44.1 | 59.1 | 32.1 | 48.7 | 20.0 | 43.4 | 37.3 | 50.5 | 28.4 | — | 119.4 |

TABLE 4.—AVERAGE SIGNAL INTENSITY AND ATMOSPHERIC DISTURBANCES FOR EL CAYEY (NAU) IN MICROVOLTS PER METER

| 1925 | A.M. | | P.M. | |
|---|---|---|---|---|
| | NAU | Dist. | NAU | Dist. |
| January | 71.1 | 9.5 | 59.3 | 8.5 |
| February | 57.2 | 15.3 | 72.2 | 22.6 |
| March | 58.2 | 22.0 | 44.2 | 44.0 |
| April | 55.1 | 25.6 | 42.4 | 77.9 |
| May | 80.3 | 28.6 | 52.4 | 77.4 |
| June | 83.3 | 25.7 | 49.1 | 129.1 |
| July | 77.6 | 28.1 | 52.1 | 104.5 |
| August | 80.2 | 15.0 | 65.0 | 91.8 |
| September | 72.2 | 22.1 | 63.9 | 46.1 |
| October | 81.5 | 26.1 | 62.6 | 35.0 |
| November | 73.0 | 16.5 | 60.7 | 23.0 |
| December | 77.0 | 21.2 | 89.7 | 22.5 |
| Average | 72.2 | 21.3 | 59.4 | 56.8 |

with the telephone comparator[5] in which a known audio-frequency signal is matched against the signal as heard in the telephones of

[5] Proc. I. R. E., 12: 521. 1924.

the receiving set. Special calibrations of the apparatus are made from time to time either by means of a local generator of from signals of known intensity. The agreement between the three systems of measurement was very satisfactory, when the disturbances were not too heavy; the differences being generally less than 20 per cent on distant signals, with still better agreement on the nearer stations.

The tables and curves[6] giving the results of the year's work at the Bureau of Standards are self-explanatory. In addition to the data for 1925, the curves show also some comparisons of the field intensities of various stations and the strength of the atmospheric disturbances

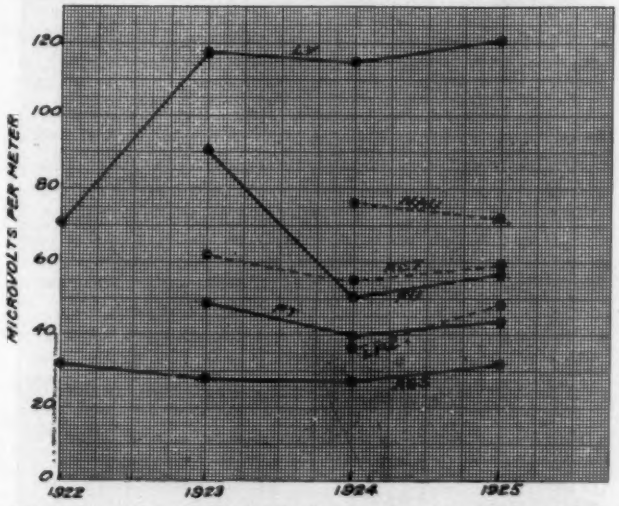


Fig. 1.—Annual average signal, 10 A.M., 1922, 1923, 1924, and 1925

in former years due to difficulty in making accurate measurements of the actual field strength of atmospheric disturbances the results shown in the curves of atmospheric disturbances are expressed in equivalent microvolts per meter.

The seasonal variations of the continental European stations as observed in Washington now seem to be fairly clear. The 10 A.M. observations give all daylight path conditions, though during the

[6] The measurements are taken when possible on moderate speed transmission, as speeds above fifty words per minute are found to reduce the received field intensity in a marked degree.

It is also to be noted that the two Ste. Assise stations formerly UFT and UFU are now FT and FU, while the old Nauen POZ is now AGS.

shortest days of winter the Nauen observations, with 6 hours difference of time, have to be taken somewhat before 10 A.M. The winter A.M. signals of the northern European stations are weak in America, owing either to the approach of sunset in Europe, or to the proximity of the arctic darkness along the signal path as suggested by Espenschied, Anderson and Bailey[7] or possibly to a combination

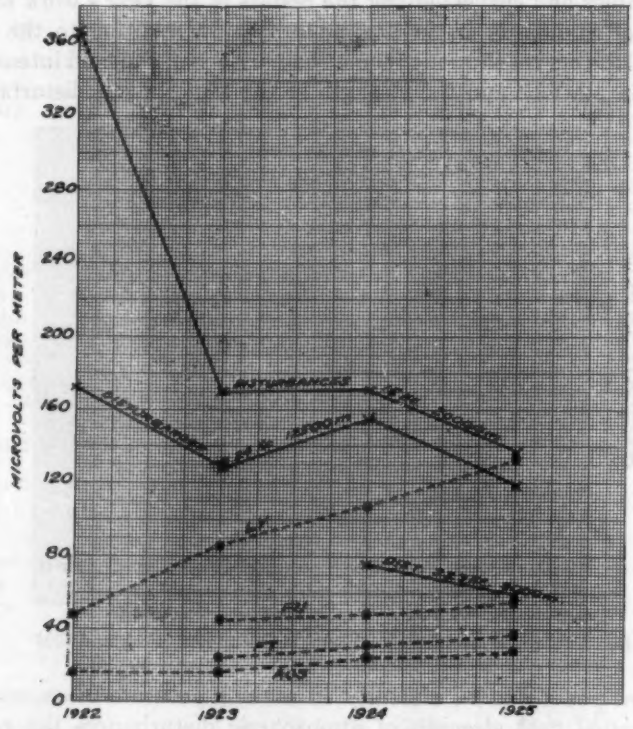


Fig. 2.—Annual average atmospheric disturbances and signal, 3 P.M., 1922, 1923, 1924, and 1925.

of these causes. The 10 A.M. signals become in general stronger through the spring and summer and reach a distinct maximum about September, after which they fall to their low winter values. The course of the 3 P.M. signals which are transmitted at about 8 P.M. in western Europe or 9 P.M. in central Europe and hence have a path of partial darkness during most of the year is the reverse of that of

[7] Proc. I. R. E., 14: 7. 1926.

the 10 A.M. all daylight signals. The maximum occurs in mid-winter with a minimum in summer. The 10 A.M. and 3 P.M. curves cross each other as a rule in March and October. The 3 P.M. winter maxima are particularly strong in the case of the longer wave stations, Bordeaux LY, Ste. Assise FU, and Nauen AGW.

This strengthening of the 3 P.M. European signals in winter, with darkness extending over part of the signal path, does not seem to

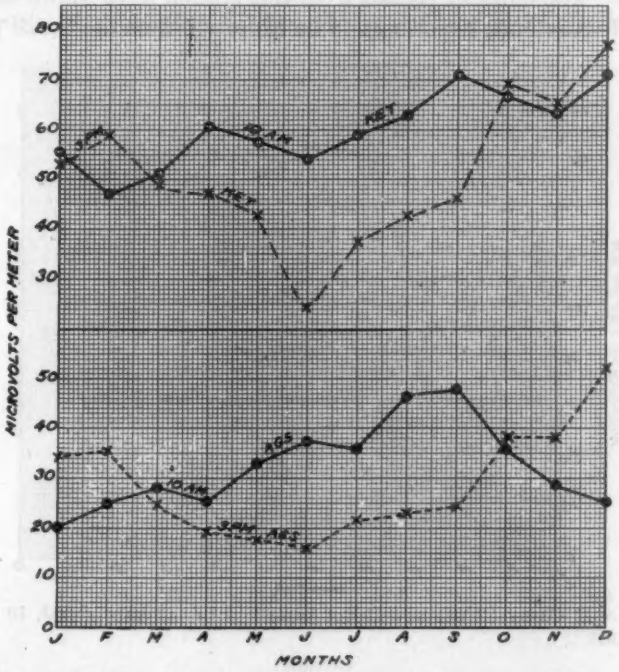


Fig. 3.—Nauen (AGS) and Bolinas (KET) average signal, 10 A.M. and 3 P.M., 1925

agree with the observations of Espenschied, Anderson and Bailey on signals between England and America, who found low intensities for partly dark signal path. We have, however, no observations on European stations of a wave length below 12,000 m., while the most pronounced drop in intensity as noted by the Bell observers was at much shorter wave lengths.

The west-east transcontinental signals from KET, Bolinas, California (three hours time difference), which have an all daylight path during both observation periods show practical equality of the 10 A.M.

and 3 P.M. signals in winter, while in summer the afternoon signals fall well below those of the morning. The same can also be said in regard to the signals of NAU, Cayey, Porto Rico (approximately south-north transmission) at a distance of 2500 km. In the case of Monte Grande, Argentina, LPZ (south-north transmission) at a distance of 8300 km. and with a little more than an hour's difference in time, there has been until recently no regular afternoon transmission. The morning signals from this station have shown no great seasonal variations, which was to be expected since the signal path is

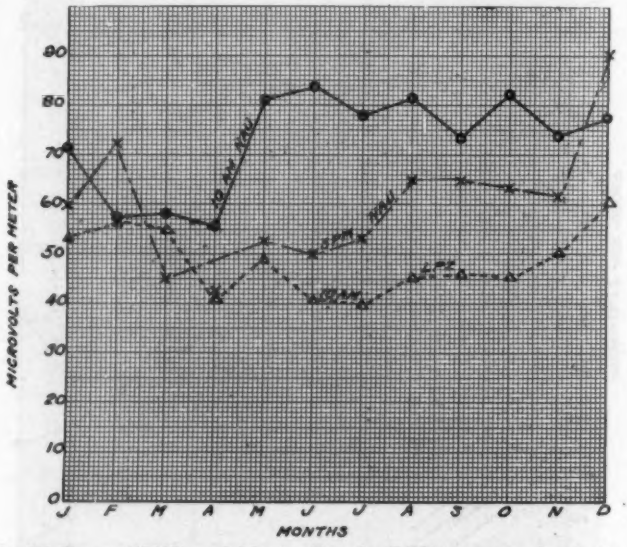


Fig. 4.—El Cayey (NAU) and Monte Grande (LPZ) average signal, 10 A.M. and 3 P.M., 1925.

divided nearly equally between the northern and southern hemispheres. From the data available it seems that the afternoon signals are much weaker than those of the morning in winter and spring, and it is probable that this difference persists throughout the year. The cause of this weakening of signals in the afternoon, which is observed on practically all stations in summer, even when there is comparatively little difference of time and no question of sunset or darkness effect, is not clear. It may be connected with absorption due to ionization in the lower atmosphere along the signal path, produced by the same conditions which produce atmospheric disturbances in the afternoon along the same path.[8]

[8] Several years ago Navy operators in Panama reported weak signals from Washington whenever bad disturbance days occurred in the eastern United States.

In Fig. 8, the monthly averages of the 3 P.M. signals from Bordeaux (LY) received in Washington and those of the corresponding signals taken at Meudon near Paris (d = 510 km.) are shown. The remarkable agreement in seasonal variation at these two receiving stations, which has not been observed in other signals taken at moderate and long distances, and which did not occur before LY's change of wave length from 23,400 m. to 18,900 m., indicates that the variations observed in Bordeaux signals are due to causes in the neighborhood of the transmitting station and not in the general trans-

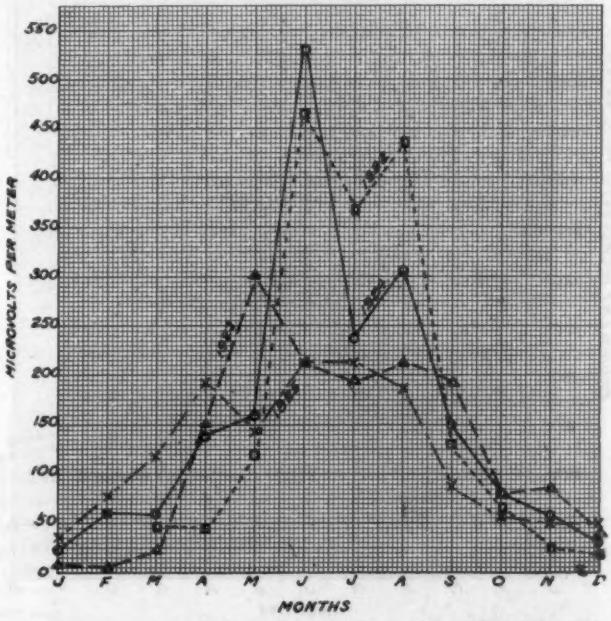


Fig. 5.—Average atmospheric disturbances, 3 P.M., for 1922, 1923, 1924, and 1925. f = 24 kc. (12500 m.).

mission paths. In addition to the agreement in seasonal variations at Washington and Meudon, it is to be noticed that there has been a gradual increase in Bordeaux's intensity at both receiving stations which is out of proportion to the average increase in antenna current.

During the year a slight modification has been made in the constants of the exponential term $e^{-\alpha}$ of the Austin-Cohen transmission formula, which has resulted in a great improvement between the observed and calculated values at the greater distances without impairing the

accuracy of the formula at moderate distances. The value of the exponent, $u$, expressed in km and wave lengths, is now

$$\frac{1.4\times10^{-3}d}{\lambda^{0.5}} \text{ instead of } \frac{1.5\times10^{-3}d}{\lambda^{0.5}}$$

where $d$ is the distance and $\lambda$ the wave length, or expressed in km. and kc., $u = 4.57\times10^{-5}\,d\times f^{0.6}$. This change approximately doubles

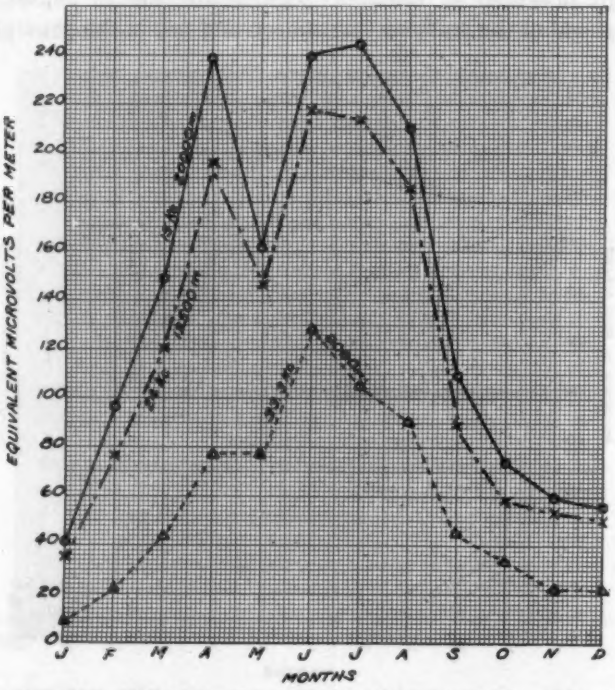


Fig. 6.—Average atmospheric disturbances 3 P.M., for 1925. f = 15 kc. (20000 m.), 24 kc. (12500 m.), and 33.3 kc. (9000 m.).

the calculated values at 6000 km. and increases them about four times at 12,000 km.

An examination is now being made of the transmission data already collected for the purpose of finding possible connections with other natural phenomena. Special study has been given to possible meteorological relations. It appears that for long distance long-wave transmission, for example between Europe and America, the connection between signal strength and American weather is not

close. This is not remarkable since the meteorological data in America can apply to only a small portion of the signal path. A much more distinct relationship exists in transmission over a few

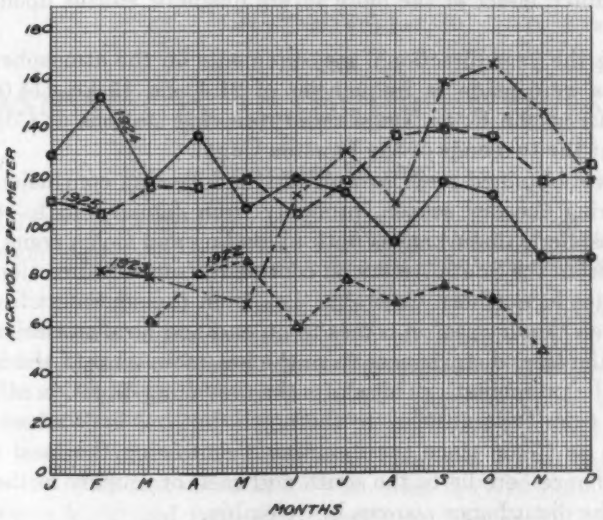


Fig. 7.—Lafayette (LY) average signal, 10 A.M., 1922, 1923, 1924, and 1925

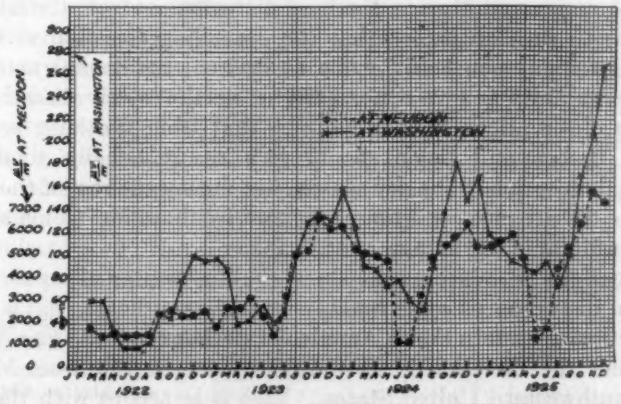


Fig. 8.—Lafayette (LY) average signal at Meudon and Washington, 3 P.M., 1922, 1923, 1924, and 1925.

hundred km. because in these cases the weather is comparatively uniform over the whole path. This will be discussed in a later report.

Comparisons have also been made between European signal in-

tensity in Washington and the occurrence of sunspots[9] and magnetic storms. Thus far no certain relationship has been observed between sunspots and abnormal signals, but there appears to be in many cases an undoubted effect of the more severe magnetic storms upon transmission.[10]

During the year directional measurements on the atmospheric disturbances were made at frequencies of 21.4 and 15 kc. (14,000 and 20,000 m.) at the U. S. Naval radio receiving stations at Colon and Balboa at the two ends of the Panama Canal.

The data obtained seem to warrant the following conclusions:

1. During the dry season, probably from January 15 to April 1, the atmospheric disturbances both at Balboa and Colon come almost entirely from the South American continent, from the direction of the high Andes in northern Colombia, i.e., from the southeast.

2. When the dry season comes to an end and local storms begin to appear, the local disturbances from the low mountains of the isthmus begin to be prominent. This shifts the prevailing direction at Balboa at times from the southeast to the north, but has little effect on the direction at Colon since the mountains containing the local centers of disturbance here lie to the south and east, or roughly in the direction of the disturbance sources in Colombia.

3. In midsummer, while there is probably much disturbance from Central America and Mexico, the local disturbances from the isthmus mask this to such an extent that the prevailing direction at Colon continues roughly southeast, while at Balboa, the distant and local disturbances unite to give a northerly or northwesterly direction.

4. The observations further indicate that from northern sending stations, Balboa and Colon should give nearly equally good unidirectional reception in the dry season, but during the rest of the year, where the disturbance conditions are more troublesome, Colon should have considerable advantage over Balboa.

Observations in Washington show that in winter the prevailing afternoon disturbances come roughly from the southeast, that is, from the direction of eastern South America or perhaps in part from Africa. In summer the direction is southwesterly, apparently from Mexico or the southwestern United States. This is in accord with the idea that disturbances generally originate over land and are most intense in the afternoon and evening in the regions where the sun passes very nearly overhead.

[9] For a complete study of the possible relationship between radio phenomena and solar activity observations covering at least one complete sunspot cycle will be necessary.

[10] ESPENSCHIED, ANDERSON and BAILEY, *loc. cit.*, have noticed in their measurement of signals between England and America that magnetic storms produce a marked decrease in night signals and a slight increase in day signals.